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A SEAWATER BATTERY MONITOR WITH FIBER OPTIC REMOTE DATA ACQUISITION CAPABILITY

by

YEON-DEOG KOO

December 1985

Thesis Advisor: John P. Powers

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A Seawater Battery Monitor with Fiber Optic Remote Date Acquisition Capability

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN PHYSICS

from the

NAVAL POSTGRADUATE SCHOOL
December 1985

ABSTRACT

This thesis presents the basic design of the system to test the voltage of a 1 volt underwater battery at a long distance by using a fiber optic system. This system contains the voltage-to-frequency converter which converts the voltage of the battery to a variable frequency pulse train, the optical transmitter, the fiber optic receiver, and a frequency-to-voltage converter which converts the variable frequency pulse train into an output voltage. This system has small error but if we use more precise components, we can get more exact result. Additionally, the lifetime of two kinds of batteries were measured by using this circuit.

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I. INTRODUCTION

A. SHORT HISTORY OF FIBER OPTICS

John Tyndall demonstrated that light was conducted in a curved path along an illuminated stream of water flowing from a hole in the side of tank in 1870. This experiment illustrated the concept of total internal reflection, wherein light rays propagate by reflection off the boundaries of a medium and escape primarily at the opposite end of the "conductor". Alexander Graham Bell was another early experimenter; in 1880, he studied the possibility of transmitting speech on a beam of light to a receiver. While the transmission of optical waves was investigated in the 1920's and 1930's, this idea was not pursued actively until the 1950's. The development of optical fibers occurred in the 1950's driven by imaging applications in the medical and nondestructive testing field. During the late 1960's, the communication aspect of fiber optics came into prominence, and the achievement of losses less than 20 db/km was announced. Rapid advancement in fiber optics technology followed.

Now fiber manufacturers are concentrating their efforts on reducing the dispersion (pulse spreading) characteristics that limit the bandwidth information capacity of this medium, operating at maximum data rate-distance products and improving performance.

B. FIBER ADVANTAGES AND DISADVANTAGES

The use of fiber optics for data transmission has many advantages. They include:

1. wide bandwidth
2. light weight
3. immunity from electromagnetic interference

4. elimination of crosstalk
5. elimination of sparking
6. compatibility with modern solid state devices
7. lower cost, and
8. no radio emission licences are required.

Also fibers have several disadvantages. They are:

1. lack of bandwidth demand
2. lack of standards for emitters and receivers, and
3. darkening in the presence of nuclear radiation.

C. THE COMPONENTS OF A FIBER OPTICS SYSTEM

A fiber optic data link comprises a fiber optic medium, a source, and a receiver. The essential factors are briefly described in the following sections.

1. Optical Fiber

This is a central cylindrical core of one index of refraction surrounded by a cladding with a slightly lower index. The confinement process that traps the light inside the fiber and allows it to propagate down the length of the fiber is based on the principle of total internal reflection at the interface of the core and cladding. Snell's law governs the transmission of the plane wave through the interface. The critical angle for total internal reflection is found to be:

$$\theta_c = \sin^{-1}(n_2/n_1) \qquad (1.1)$$

For the angles of incidence equal or exceeding the critical angle, the energy of the incident wave is totally reflected back into the core (Figure 1.1)

Two types of fibers are made. One is the step index fiber and another is the graded index fiber. Figures 1.1 and 1.2 show a sideview and refractive index profile for a step index fiber and a graded index fiber respectively.

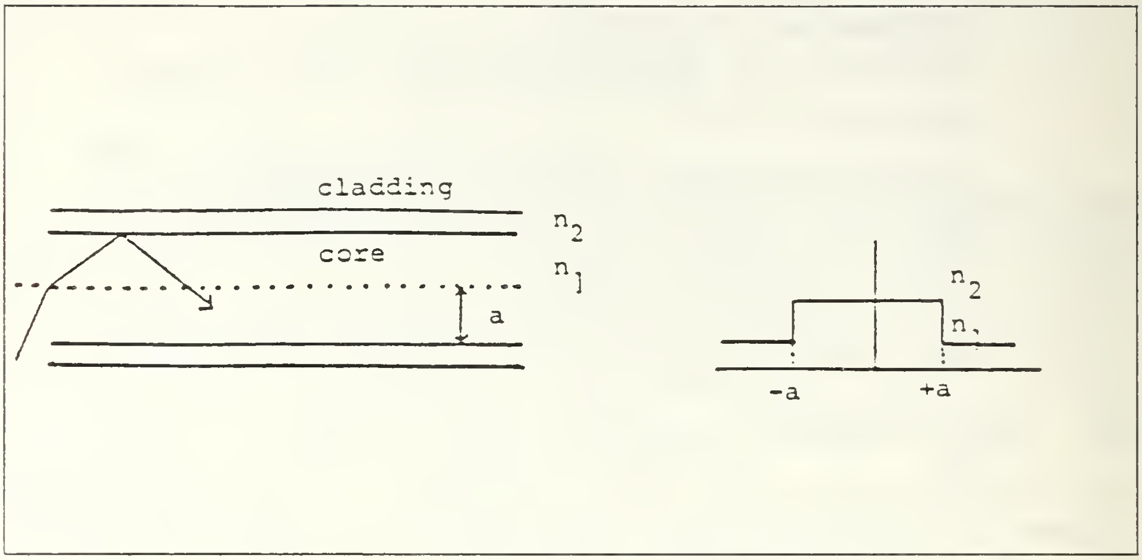


Figure 1.1 The Step Index Fiber and Index of Refraction Profile.

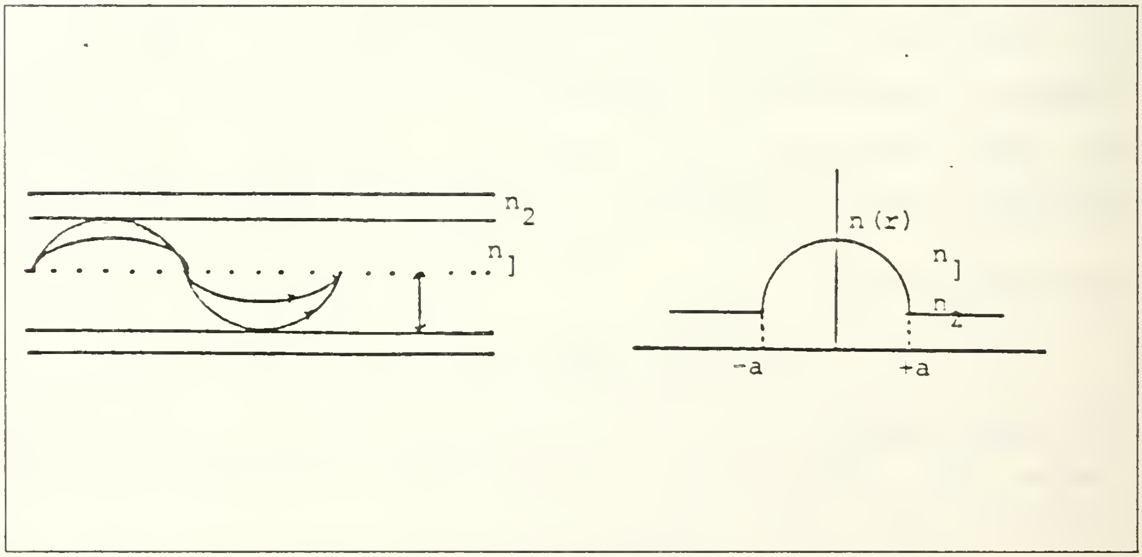


Figure 1.2 The Graded Index Fiber and Index of Refraction Profile.

2. Optical Sources

The sources currently used with fiber optics are semiconductor light sources: light emitting diodes (LED) or

semiconductor lasers. Sources are currently classified according to their wavelength. Short wavelength sources produce light in the region between 500 and 1000 nm and long wavelength sources operate in the region from 1200 to 1600 nm.

The light emitting diodes have two kinds of emitters: the surface emitter and the edge emitter. The emitting region of the surface emitter is circularly symmetric with a typical 60 degree half angle beam divergence. The emitting region of the edge emitter is asymmetric. The beam cross-section perpendicular to the junction has a typical half angle divergence of 60 degrees and the cross section parallel to the junction typically has a 30 degree half angle. The narrow beam divergence of the edge emitter improves coupling efficiency into the fiber. Edge emitters typically produce less power (approximately 1/2 to 1/6 the power) than surface emitters. The wavelength of the emitter is determined by the material composition of the emitter.

The laser diode source has a structure like that of an LED but has mirrored ends to form an optical resonator. A laser diode source has a narrower linewidth and a smaller beam divergence than an LED. It is used for long distance systems. A laser diode has the disadvantages of high expense, more degree of nonlinearity in its output characteristics and a relatively high temperature dependence that frequently requires temperature stabilization circuitry.

3. Optical Receivers

In fiber optics systems, the most commonly used receivers utilize photodiodes (either PIN or avalanche types) to convert incident light into electrical energy. A PIN photodiode consists of a large intrinsic region sandwiched between p and n-doped semiconducting regions. Photons absorbed in this region create electron-hole pairs that are then separated by an electric field, thus

generating an electric current in the load circuit. An avalanche photodiode (APD) is designed for applications requiring greater sensitivity. Because of a strong electric field arising within it as a result of external biasing, the APD exhibits an internal gain mechanism due to the generation of new carriers by a collision process. The APD can have ten to one hundred times the responsivity of photodiode.

D. THE CONCEPTS OF SYSTEM

The system investigated in this thesis is designed for the purpose of measuring the voltage of an underwater battery by using a fiber optics system. Because the battery is in deep water, we want to monitor this battery from a long distance. If a long wire is used, correct data cannot be received because of resistance in the wire itself. The system studied converts the voltage of the battery to a variable frequency pulse train that is transmitted through the fiber. The receiver converts the frequency to an output voltage that equals (or is proportional to) the battery voltage. This system consists of a voltage-to-frequency converter, the fiber optic link, a frequency-to-voltage converter, and output display on recorder as shown in Figure 1.3.

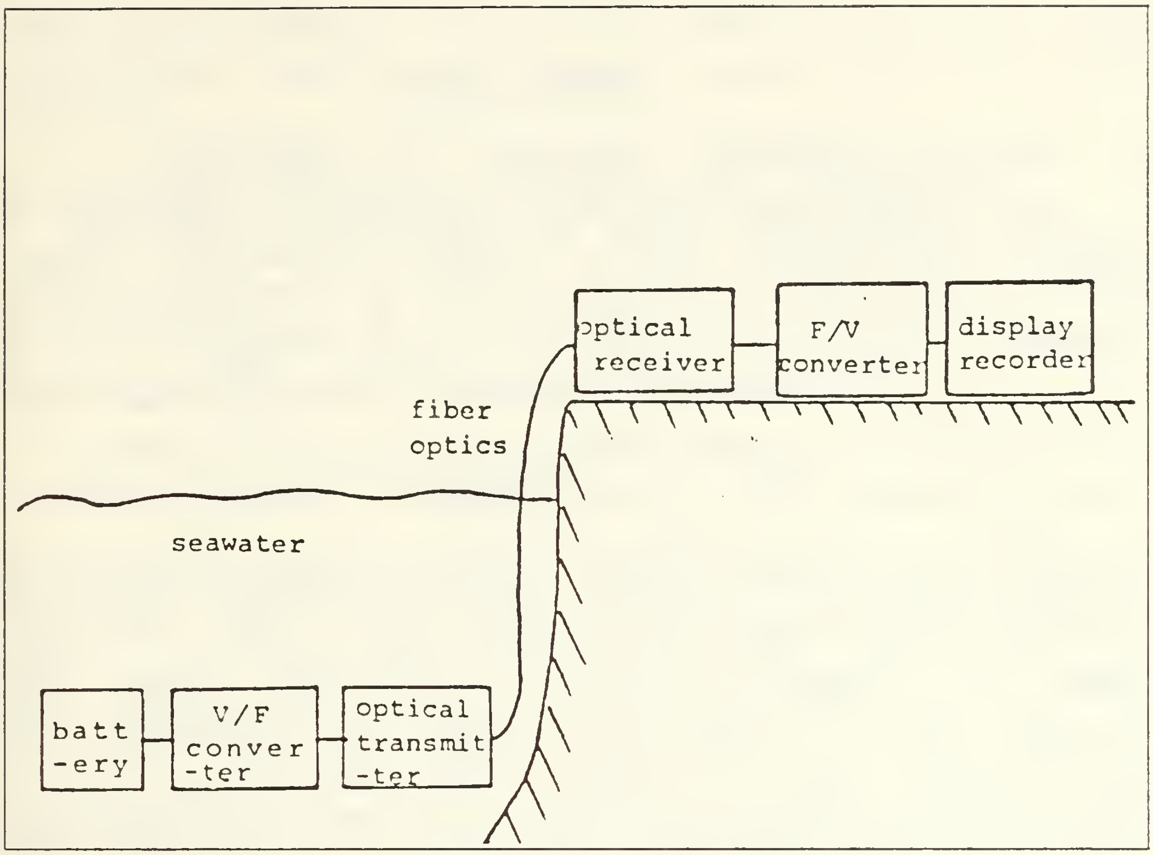


Figure 1.3   Concept of the System.

The variable frequency signal out of the V/F converter is a pulse train that intensity modulates the light wave from the transmitter of the fiber system. The frequency-to-voltage converter receives the detected pulse wave and converts it to voltage. The distance transmitted depends on the transmitter, the receiver and the kind of fiber. In this system, the battery to be tested is a 1 volt seawater battery built for a special purpose, but the system can monitor a 1 volt to a 10 volt battery without any additional components.

II. SYSTEM DESIGN

A. VOLTAGE TO FREQUENCY CONVERTER (V/F CONVERTER)

Since commercial fiber optic systems are optimized for digital transmission, the dc voltage of the test battery will be converted to a frequency by the V/F converter. The circuit of the V/F converter is shown Figure 2.1. It converts an input voltage which is in the range from 1 volt to 10 volt to a variable frequency pulse train ranging from 1 kHz to 10kHz. The LM 331 voltage-to-frequency converter is ideally suited for use in simple low cost circuits for analog-to-digital conversion, precision frequency-to-voltage conversion, and other applications. The output is a pulse train at a frequency proportional to the applied input voltage. The LM 331 utilizes a temperature compensated band gap reference circuit to provide excellent accuracy over the full operating temperature range and its operating ambient temperature range is 0°C to 75°C. Figure 2.1 shows a simple stand-alone V/F converter with 0.3 % typical linearity. In the Ref. 1, a 47Ω resistor, in series with 1 μF capacitor is suggested to give hysteresis effect which helps the input comparator provide the increased linearity (0.03 % typical) if desired. This extra circuit was not used for this work. The frequency out of the circuit of Figure 2.1 is related to the input voltage by,

$$F_{out} = \frac{V_{in}}{2.09V_s} \frac{R_s}{R_L} \frac{1}{R_t C_t} \qquad (2.1)$$

The 5k gain adjust is adjusted to scale the desired input voltage and output frequency relation. Particularly, the 5 volt input should correspond to a 5 kHz output. The circuit of Figure 2.1 was built and tested. The measured transfer characteristic of this circuit is shown in Figure 2.2 from

the data of Table I. This curve shows the desired linear relationship between the input voltage and the output frequency.

B. FREQUENCY TO VOLTAGE CONVERTER (F/V CONVERTER)

The F/V converter receives the variable frequency square wave and converts it to a dc voltage. This F/V converter circuit is shown in Figure 2.3. The output voltage is related to the input frequency by the formula,

$$V_{out} = F_{in}(2.09V_s)\left(\frac{R_L}{R_s}\right)R_tC_t \qquad (2.2)$$

The output voltage should be linearly dependent on the input frequency. The 5 KΩ resistor is adjusted to get a 5 volt output with 5 kHz input. As the input frequency is changed from 1 kHz to 10 kHz, an output voltage can be obtained from 1 volt to 10 volts. The measured response of the circuit fabricated from Figure 2.3 is shown in Table II and Figure 2.4. This circuit also shows the desired linear relationship between the output voltage and the input frequency.

If a wire is connected between the output of the V/F and input of the F/V circuits (Figure 2.5), the output voltage of the combined circuit should be approximately equal to the input voltage. The results of measurement of the combined circuits is given in Table III and Figure 2.6. As expected, the relationship is linear.

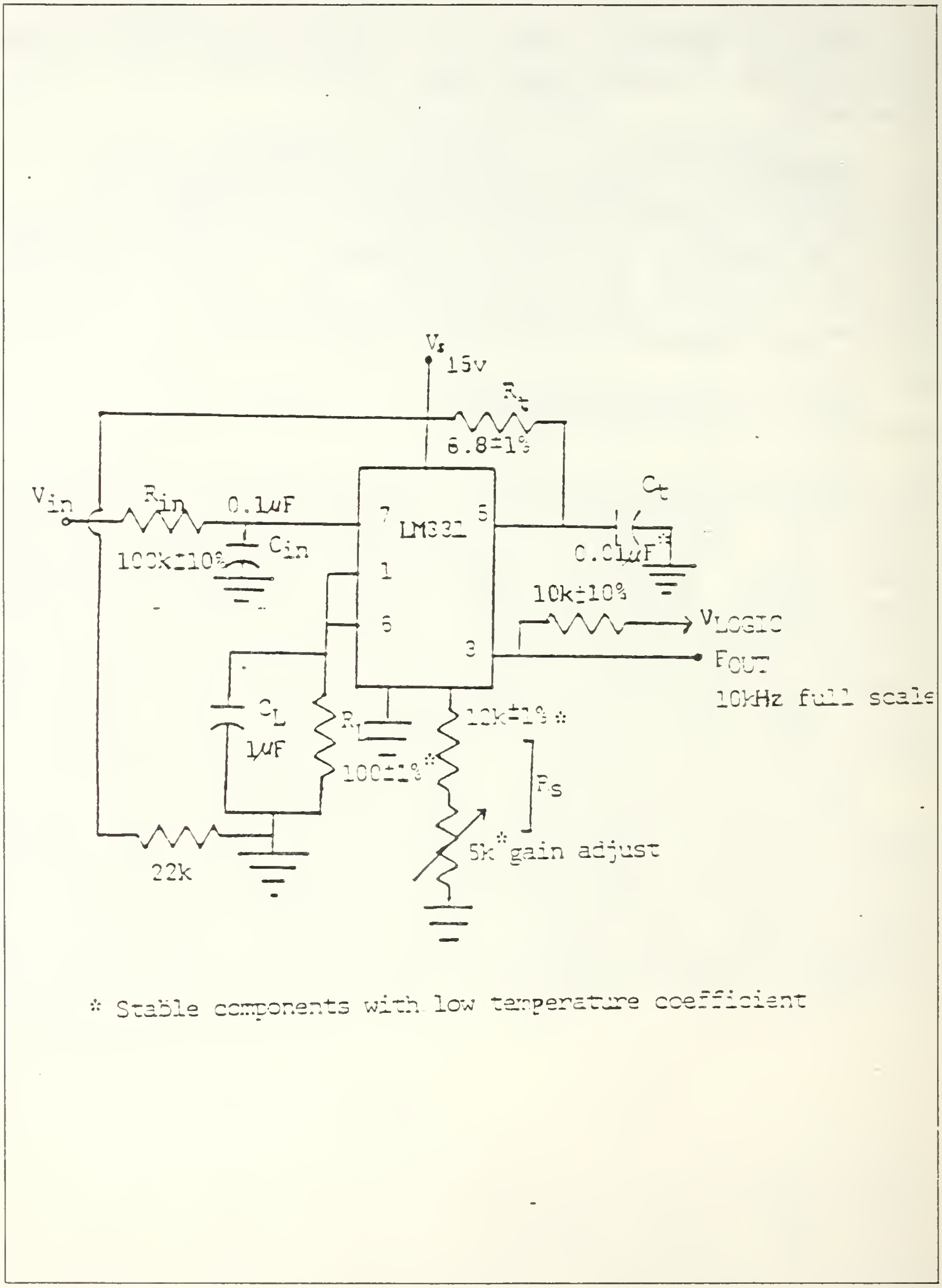


Figure 2.1 Voltage to Frequency Converter (from Ref. 1).

TABLE I

INPUT VOLTAGE VS. OUTPUT FREQUENCY

Input voltage (volt)	Output frequency (kHz)
0.02	0.02
0.50	0.50
1.00	1.05
1.50	1.54
2.00	2.01
2.50	2.50
3.00	3.00
3.50	3.50
4.00	4.00
4.50	4.49
5.00	5.00
5.50	5.50
6.00	6.00
6.50	6.49
7.00	7.00
7.50	7.50
8.00	7.99
8.50	8.49
9.00	8.99
9.50	9.48
10.00	9.98
10.50	10.48

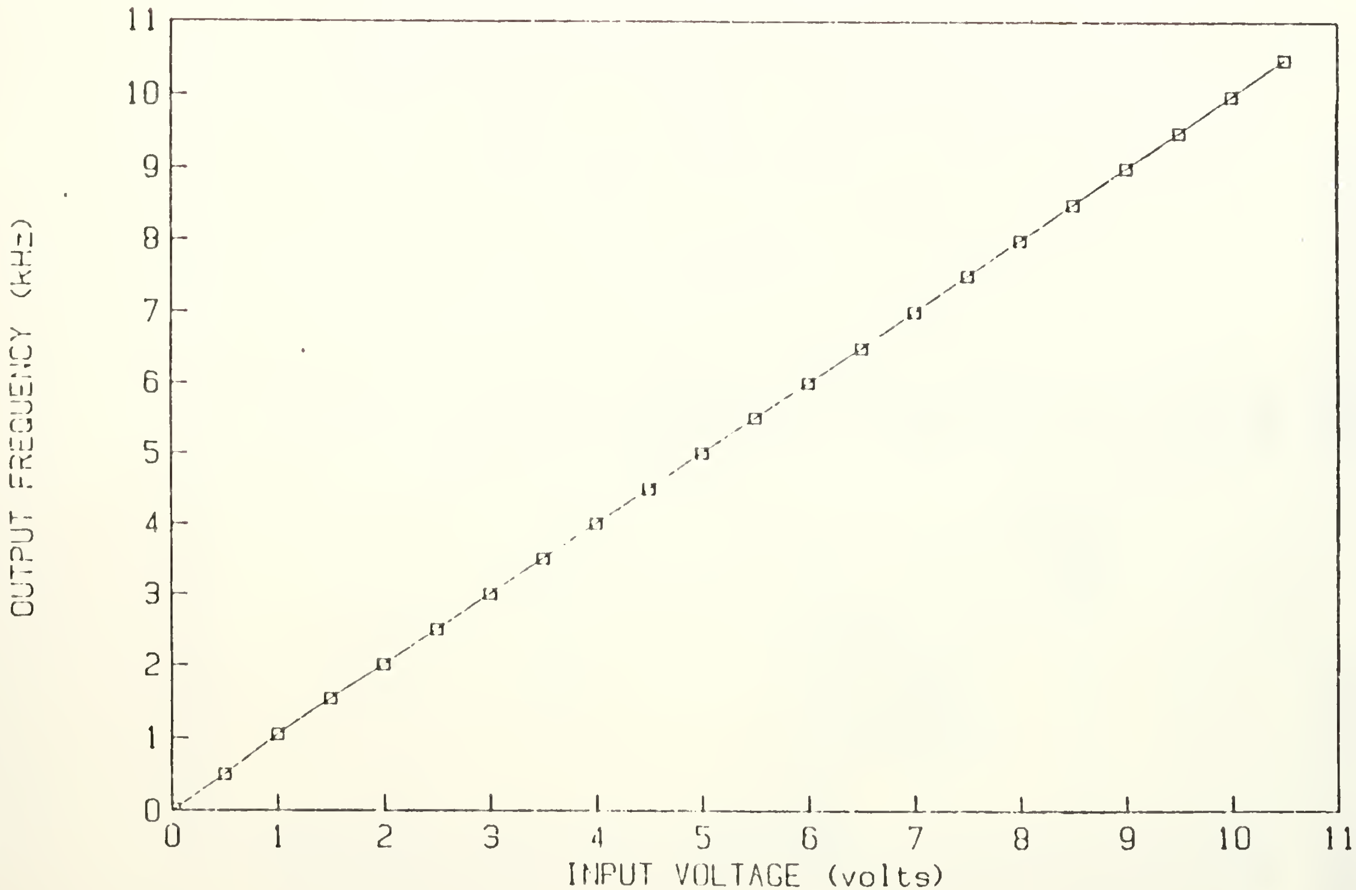


Figure 2.2 Test of V/F Converter.

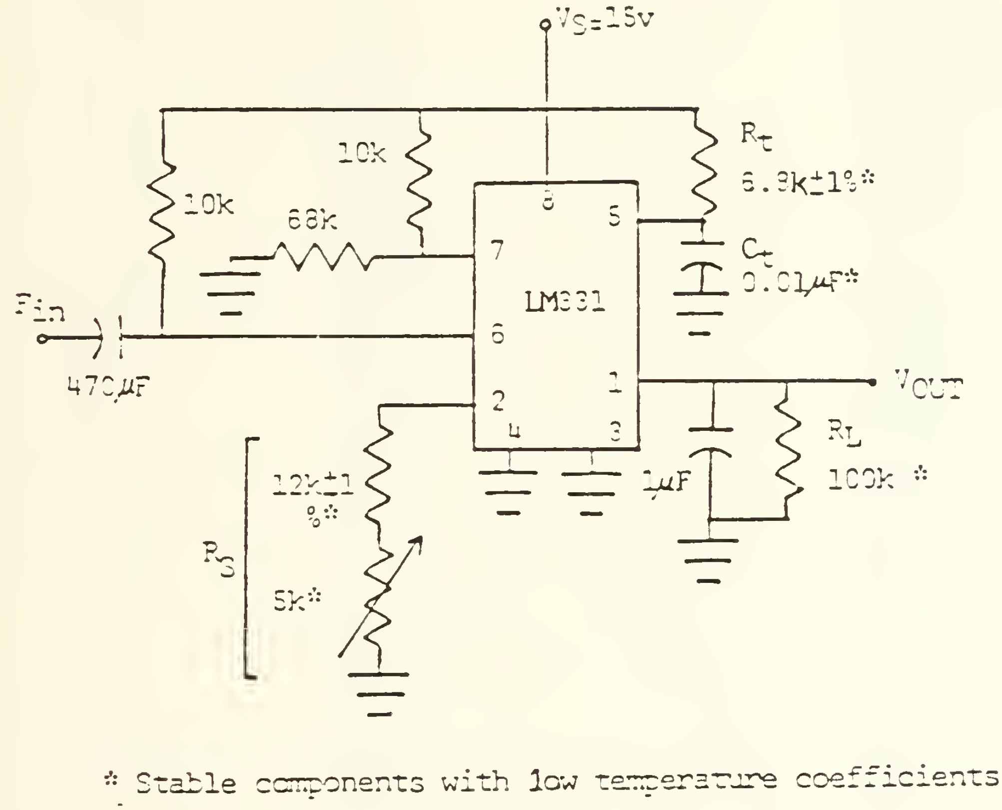


Figure 2.3 F/V Converter 10kHz Full Scale (from Ref 1).

TABLE II

INPUT FREQUENCY VS. OUTPUT VOLTAGE

Input frequency (kHz)	Output voltage (volt)
0.40	0.40
0.99	0.99
1.49	1.49
1.99	1.99
2.48	2.48
3.00	3.00
3.48	3.48
3.97	3.97
4.51	4.52
5.05	5.05
5.50	5.50
6.00	5.98
6.49	6.50
7.00	7.00
7.50	7.51
7.99	7.99
8.51	8.51
8.99	9.00
9.53	9.51
10.03	10.02
10.50	10.49

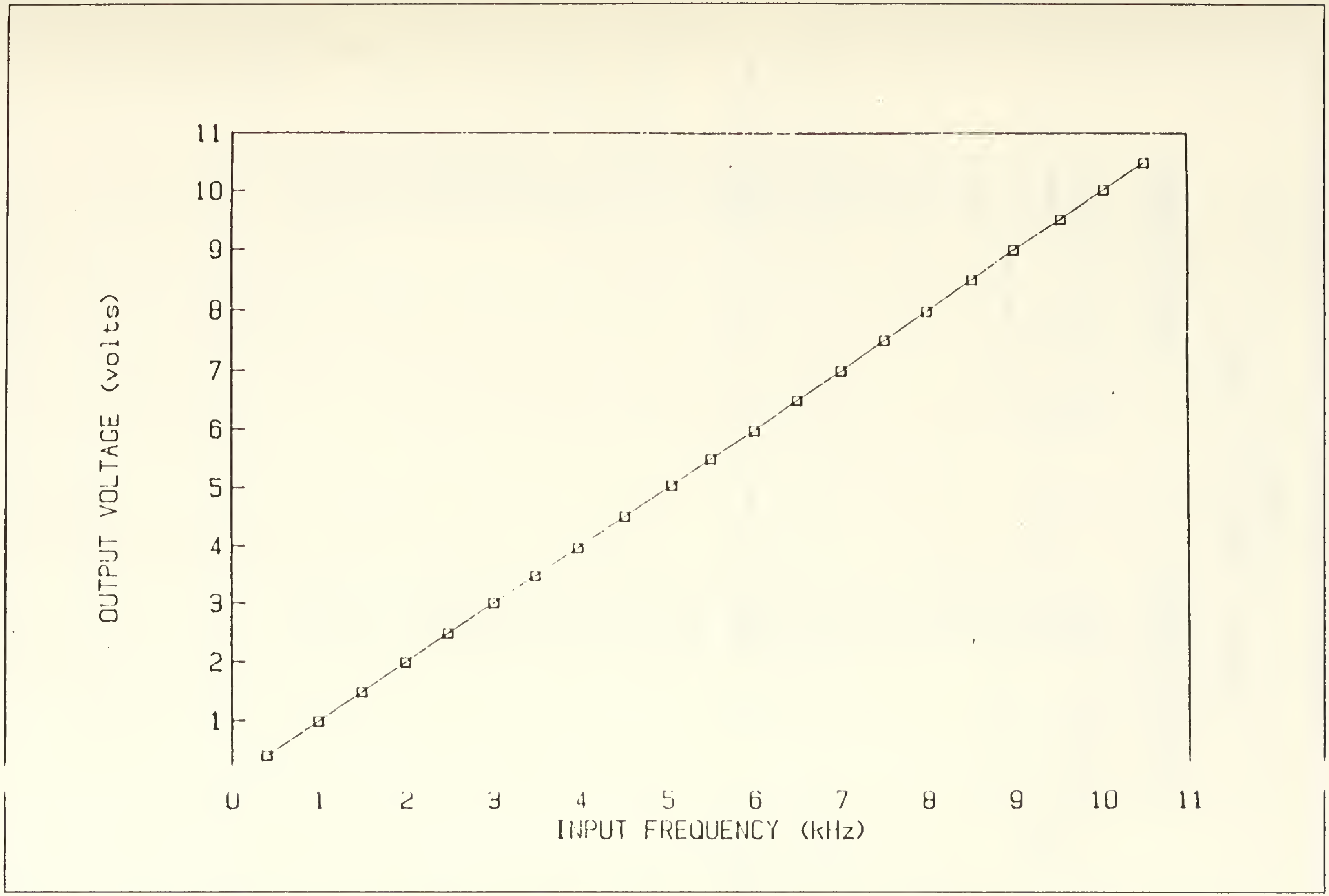


Figure 2.4 Test of F/V Converter.

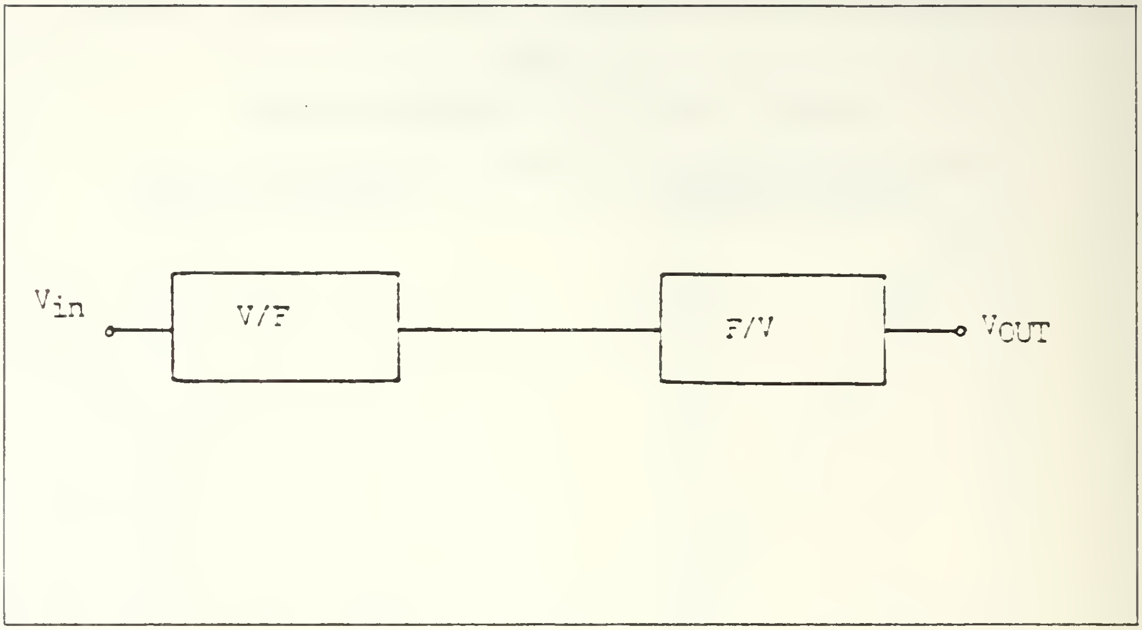


Figure 2.5 The Test System of V/F and F/V Combination.

TABLE III

INPUT VS. OUTPUT VOLTAGE

Input voltage (volt)	Output voltage (volt)
0.50	0.50
1.00	1.00
1.50	1.50
2.00	2.00
2.50	2.50
3.00	3.00
3.50	3.50
4.00	4.00
4.50	4.50
5.00	5.00
5.50	5.50
6.00	6.00
6.50	6.50
7.00	7.00
7.50	7.49
8.00	7.98
8.50	8.48
9.00	8.97
9.50	9.46
10.00	9.95
10.50	10.44

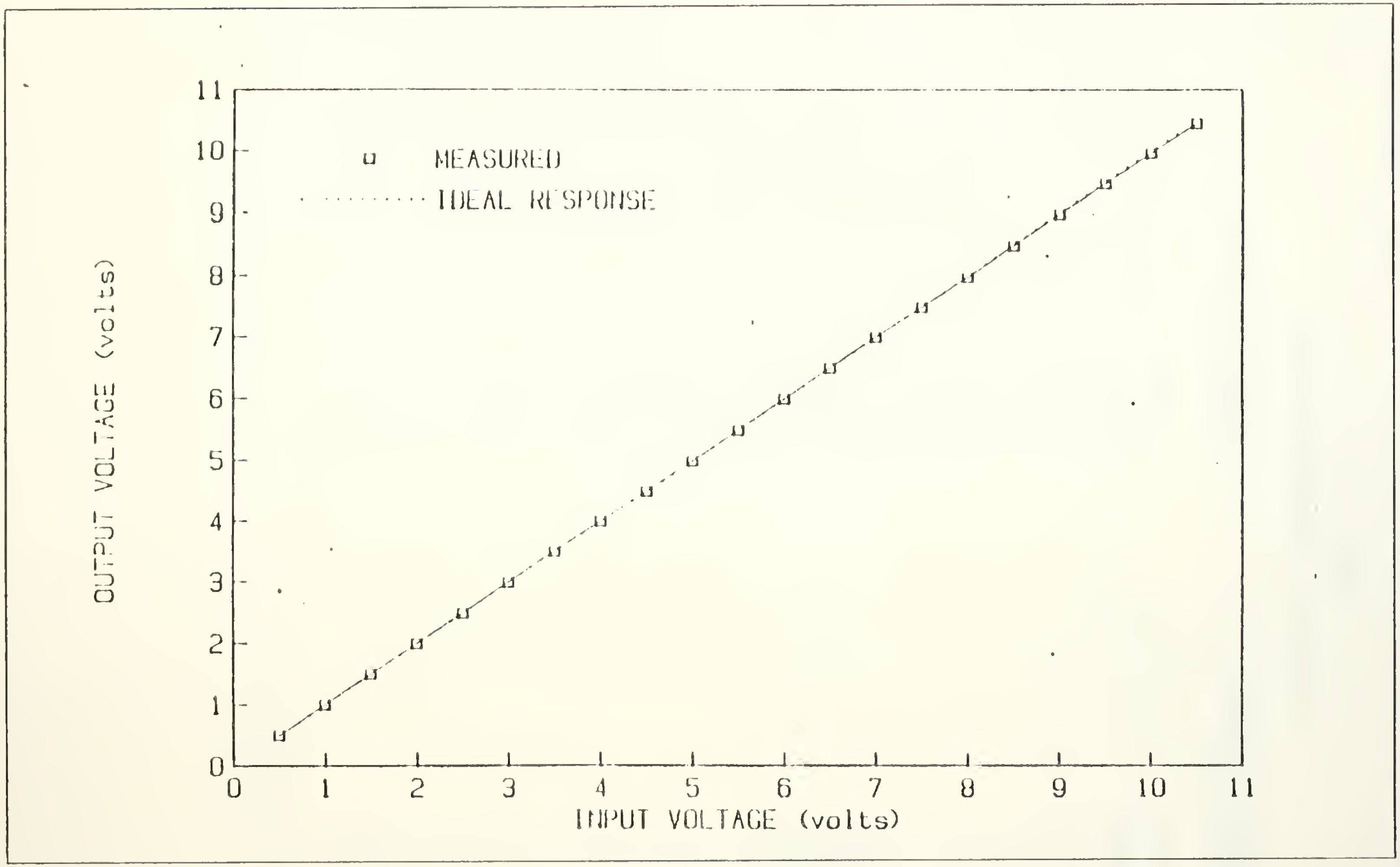


Figure 2.6 Test of V/F and F/V Combination.

C. FIBER OPTIC LINK

To determine the operating performance of the fiber optic system, a flux budget is calculated based on the transmitter output flux, receiver sensitivity and the losses of the interconnecting elements. For the system to operate satisfactorily, the total system losses must not exceed the difference of the transmitter output flux and receiver optical input sensitivity. Losses depend on the distance of the link and the condition of the fiber. Losses also include input coupling loss between the source and the fiber, connector and splice loss, attenuation loss within the fiber, and output coupling loss. Losses should always be checked. The receiver input sensitivity is the most important. If the receiver has good sensitivity, it will be possible to measure the voltage at a long distance.

1. Transmitter

The transmitter circuit is shown in Figure 2.7a. The HFBR-0500 series fiber optics system has been designed to use an all-plastic fiber optic cable for short distance digital data transmission and has numerous innovative features. The transmitter and receiver modules have jaws that grip the color coded cable connectors. Alignment at the connector/module interface is assured by mating the tapered connector with a funnel-shaped hole in the module. The alignment tolerance is minimized and area matching of the active area to the fiber core is maximized by the use of the lenses molded into the plastic encapsulation. The gray HFBR-1501 transmitter module (Figure 2.7b) houses a 665 nm large area LED emitter that can easily be driven by standard logics gates. For long distance transmission where more current may be required to obtain higher optical flux output, a standard high current line driver, the SN 75451 (Figure 2.7c), is used to supply the required current. A shunt driver current of Figure 2.7a has the advantage of a

continuous power supply current drain and less power supply noise is generated. A shunt drive circuit can also be used with a low power supply voltage and is recommended when driving single LED's.

For laboratory testing of the design a short distance link is suitable. For actual undersea implementation, a better source/receiver combination and lower loss fiber would be used to achieve data transmission.

The value of the transmitter driver current, I_f, must be determined from the graph of Figure 2.8. Note that there is an upper as well as a lower limit on the value of I_f for any given distance. The dotted line represents pulsed operation. After selecting a value for the transmitter drive current I_f, the value of R_1 in Figure 2.7a can be calculated as follows:

$$R_1 = (V_{cc}-V_f)/I_f \qquad (2.3)$$

Where V_f is the forward drop across the source and is found from the transmitter data. The measured value of V_f is 1.60 V. The current I_f was chosen to be 0.33 mA for this design. The supply voltage V_{cc} is 5 V. Hence $R_1 = (5-1.60)/(0.33\text{mA}) = 10.30\ \text{k}\Omega$. A variable resistor was used for R_1 and it was changed to get the desired value of I_f. The pulse wave which goes through the SN75451 turns the light of the transmitter on and off as a logic gate. The transmitted wave form is sketched in Figure 2.9.

The detected waveform at the receiver end of the fiber is shown in Figures 2.10-2.12. Figure 2.10 shows the wave through the fiber optics when the input dc voltage is 1 volt, and the output frequency of V/F is 1 kHz. Because 1 division is 0.1 msec, the period of the wave is 1 msec, which corresponds to the expected value of the period of 1 kHz. Vertically, each division is 0.5 volt, with the detector calibrated so that 1μw corresponds to 1 volt out.

We can determine the power of the transmitted light from the measured detector voltage of 1.05 volts. Hence, the power of the transmitted light is 1.05 μw. If a different transmitter or optical fiber is used, the power will be different. Also, the detected power depends on the loss of the fiber system. Figures 2.11 and 2.12 show a waveform when the transmitted frequency is 5 kHz and 10 kHz. The wave frequency increases, but the peak power of the light pulse is observed to be constant and does not depend on input frequency.

2. Receiver

The blue plastic HFBR 2500 receiver module features a shielded integrated photodetector and a wide bandwidth DC amplifier for high EMI immunity. An integrated 1000Ω resistor internally connected to V_{cc} may be externally jumpered to provide a pull-up for ease-of-use with 5 v logic. The HFBR-2500 receiver has been designed as a monolithic detector and amplifier with an internal shield protecting the sensitive internal circuitry and has been found to provide greater EMI immunity than unshielded parts. The power supply required for the receiver modules is 5 Vdc, making the module compatible with the popular 5 V logic families. The receiver circuit is shown in Figure 2.13.

After the transmitter and receiver circuits were made, their performance was measured. To obtain good linearity the variable resistor of V/F and F/V were adjusted to equalize the input and output voltages. Figure 2.14 shows the circuit of the complete fiber optic link. The results of measured performance are given in Table IV and plotted in Figure 2.15. The result shows that the input voltage and the output voltage are the same.

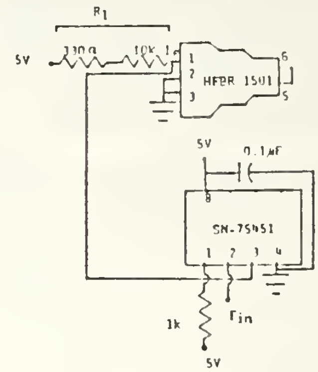


Figure 2.7a Optical Transmitter Circuit (from Ref. 2).

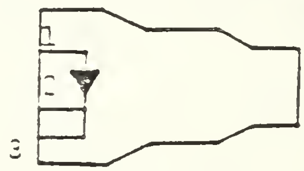


Figure 2.7b HFBR 1501 Pin Connection.

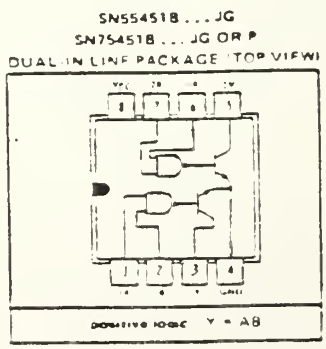


Figure 2.7c SN 75451 Drive Circuit Pin Connections (from Ref. 3).

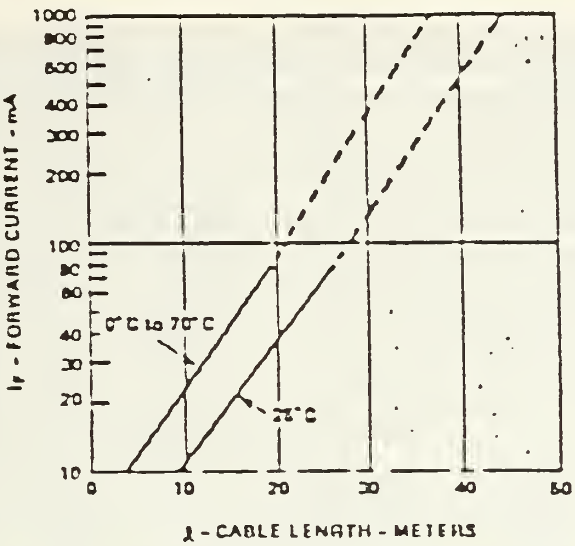


Figure 2.8 System Performance with HFBR-1501 and 2501 (from Ref. 2).

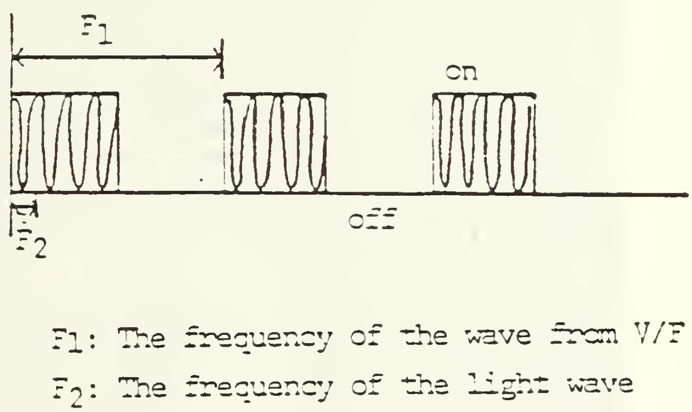
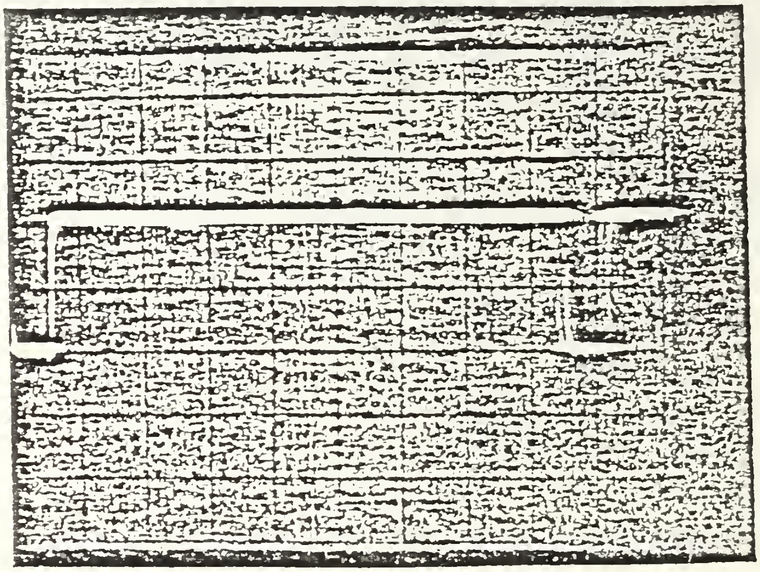


Figure 2.9 Transmitted Waveform.



Horizontal 0.1msec/div
Vertical 0.5 V/div
1 V out/1μw in

Figure 2.10 Detected Waveform (Frequency: 1kHz).

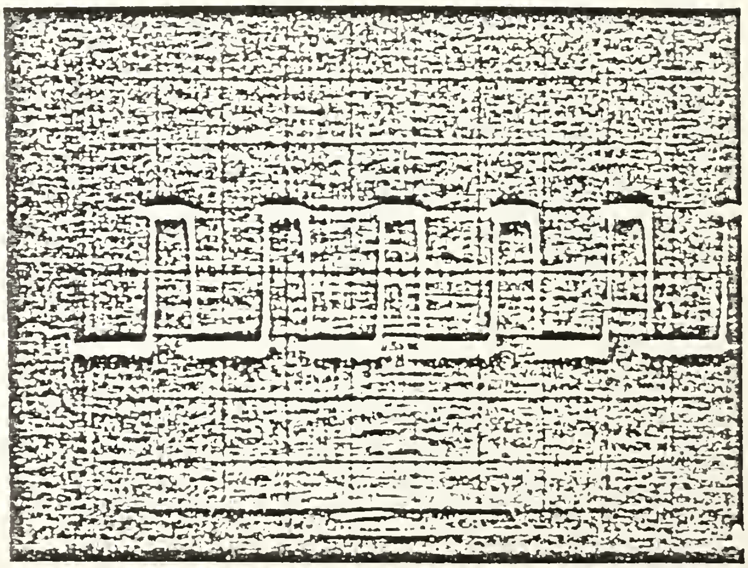


Figure 2.11 Detected Waveform (Frequency: 5kHz).

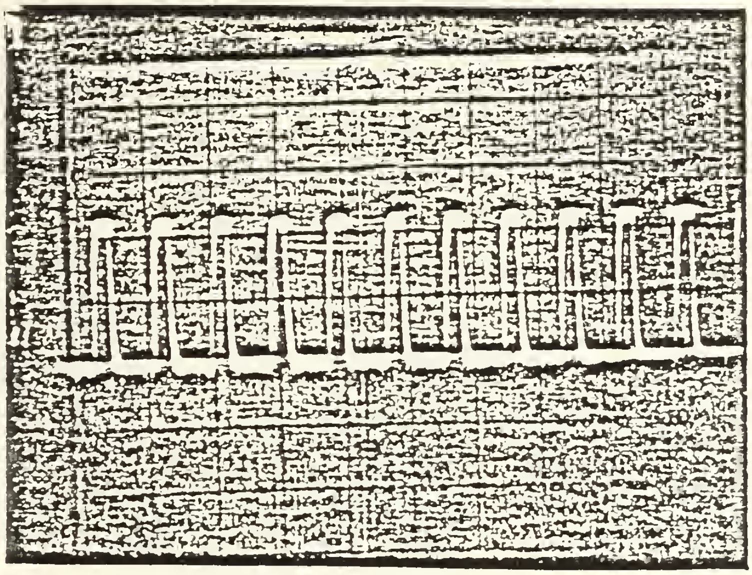


Figure 2.12 Detected Waveform (Frequency: 10kHz).

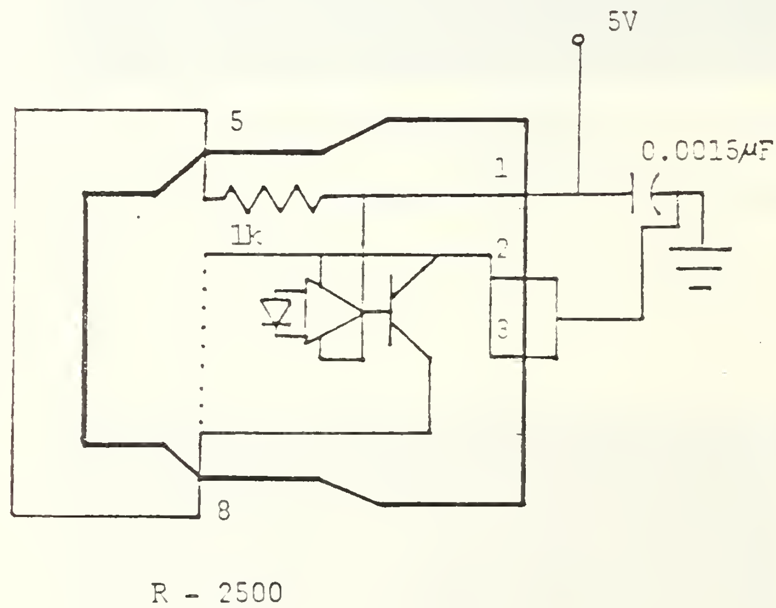


Figure 2.13 Optical Receiver Circuit.

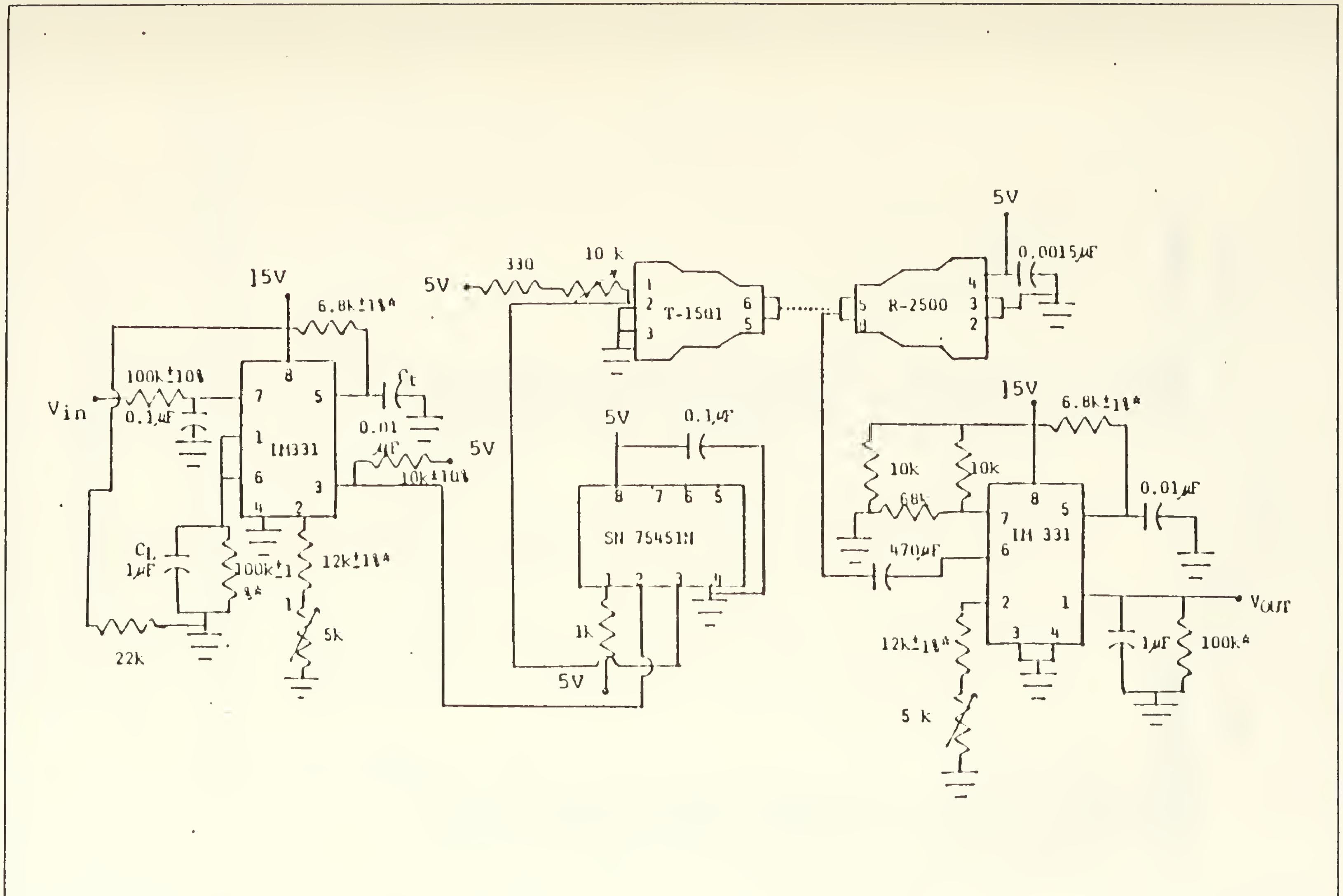


Figure 2.14 The Circuit with Fiber Optics Link.

TABLE IV

INPUT VOLTAGE VS. OUTPUT VOLTAGE

Input voltage (volt)	Output voltage (volt)
1.00	1.00
1.50	1.51
2.00	2.00
2.50	2.50
3.00	3.01
4.00	4.00
4.50	4.51
5.00	5.00
5.50	5.50
6.00	6.00
6.50	6.49
7.00	6.99
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9.50	9.50
10.00	10.00

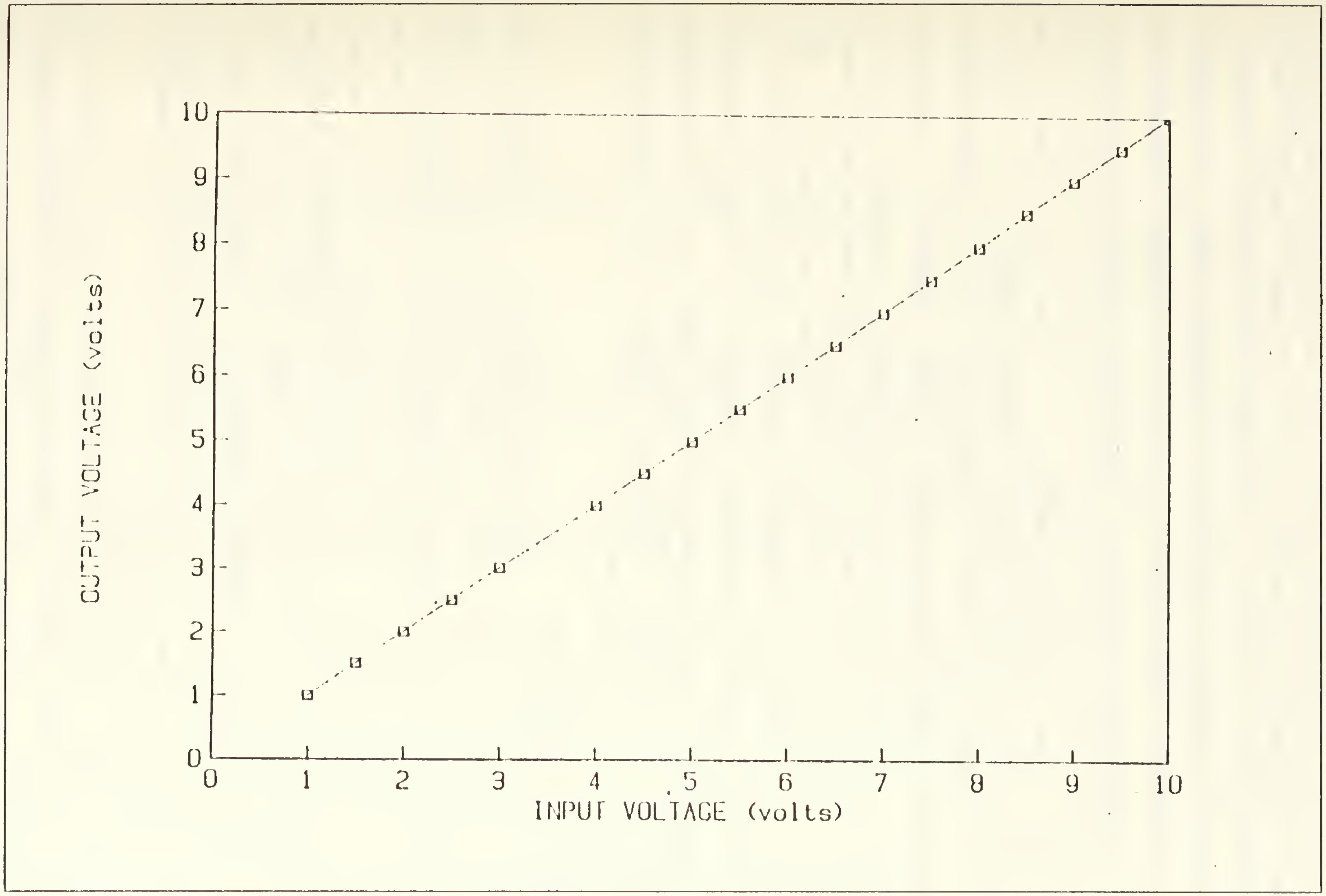

Figure 2.15 Test Results for Complete Optical Link.

When calculating the system link performance of any system, tolerance variations and the dynamic range of each component add to limit the worst case transmission distance. While most tolerance variations are determined by manufacturing limits, some variation can be expected, especially due to temperature effects. Temperature effects can account for greater than 2 db or 1/3 of transmitter's output flux variation. One possible method of providing temperature compensation is to use the base emitter junction of transmitter to match the LED's temperature drift. Temperature compensation was used in this study, however. In this system, the data measured in laboratory in mid afternoon (high temperature) and early morning (low temperature) was slightly different. The output voltage measured in mid afternoon was slightly higher than the voltage measured in early morning for the same input voltage. In deep sea water the temperature differences are not large, as the ambient temperature is almost constant. Hence, the temperature compensation was neglected.

D. VOLTAGE REGULATORS

The power for the electronic circuits is taken from voltage regulators included on the circuit board. The LM 341 series of three terminal regulators is available with several fixed output voltages making them useful in wide range of applications. The characteristics for an output voltage of 15 V include an operating temperature ranging from 0°C to 70°C and an input voltage ranging from 17.6 to 30 V. The LM 7805 3-terminal regulator is available with 5 volt output voltage. Its characteristic includes an input voltage ranging from 7 V to 25 V and an operating temperature range of 0°C and to 70°C.

An LM 7805 and LM 341 were added to each circuit to provide regulated power. The performance of these regulators as the input voltage is changed is found in Table V and

plotted in Figure 2.16. This performance is particularly important for the wet end of the link as batteries will be used to power this component. As seen in the Figure 2.16, when the input voltage of LM 341 is above 16 volts, the output voltages of the LM 341 and LM 7805 were good.

TABLE V

MEASUREMENT OF LM 341 AND LM 7805

V_{in}	V_{cc} of V/F		V_{cc} of F/V	
	LM 341	LM 7805	LM 341	LM 7805
(volt)	(volt)	(volt)	(volt)	(volt)
12	10.5	4.97	10.53	4.95
13	11.46	4.97	11.51	5.01
14	12.46	4.98	12.46	4.96
15	13.40	4.97	13.45	5.01
16	14.41	4.97	14.02	5.02
16.5	14.36	4.96	14.10	4.99
17	14.54	4.96	14.36	5.01
18	14.30	4.92	14.73	5.00
19	14.89	4.95	14.81	5.02

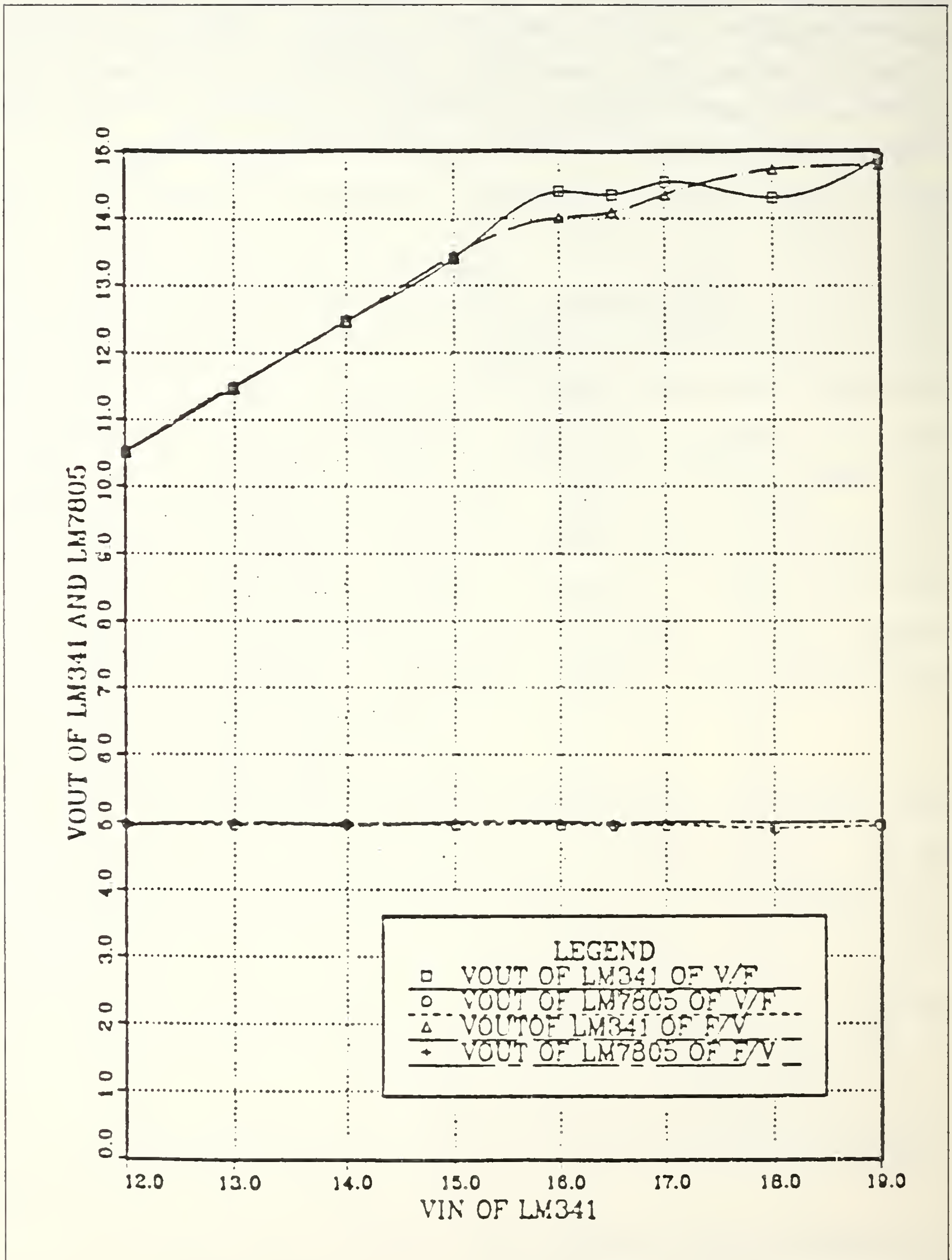

Figure 2.16 The Measurement of Reasonable Input Voltage.

E. VOLTAGE PRESCALER

As described, the link can measure a battery of 10 volts maximum. Since the seawater battery is expected to produce a nominal output voltage of 1 volt, a circuit which can measure the battery of 1 volt maximum is required. This problem will be solved if a prescaling amplifier with a gain of 10 is added to the input of the V/F circuit. A circuit for such an amplifier is shown in Figure 2.17a and 2.17b which are taken from Ref. 4. This amplifier has high input impedance, low output impedance and a stable voltage gain given by $V_{out}/V_{in} = (R_2/R_1)+1$. To balance the bias conditions, we require $R_3 = R_1 // R_2$. Because V_{out}/V_{in} is 10, $R_2/R_1 = 9$. If R_1 is selected by 10 kΩ, R_2 = 90 kΩ, and R_3 is 9 kΩ. The LM 318 was selected for an operational amplifier. Its connection diagram is shown in Figure 2.17b (Ref. 4). The LM 318 is a precision high speed operational amplifier designed for applications requiring wide bandwidth and high slow rates. The features of LM 318 include:

1. Supply voltage: 5 V to 20 V
2. Maximum input voltage: 15 V
3. Operating temperature range: 0°C - 70°C
4. For supply voltage less than 15 V, the absolute maximum input voltage is equal to the supply voltage.

The completed diagram of the amplifier is shown in Figure 2.17b. The measured data is in Table VI and Figure 2.18 showing a constant gain of 10 for input voltages up to 1 volt.

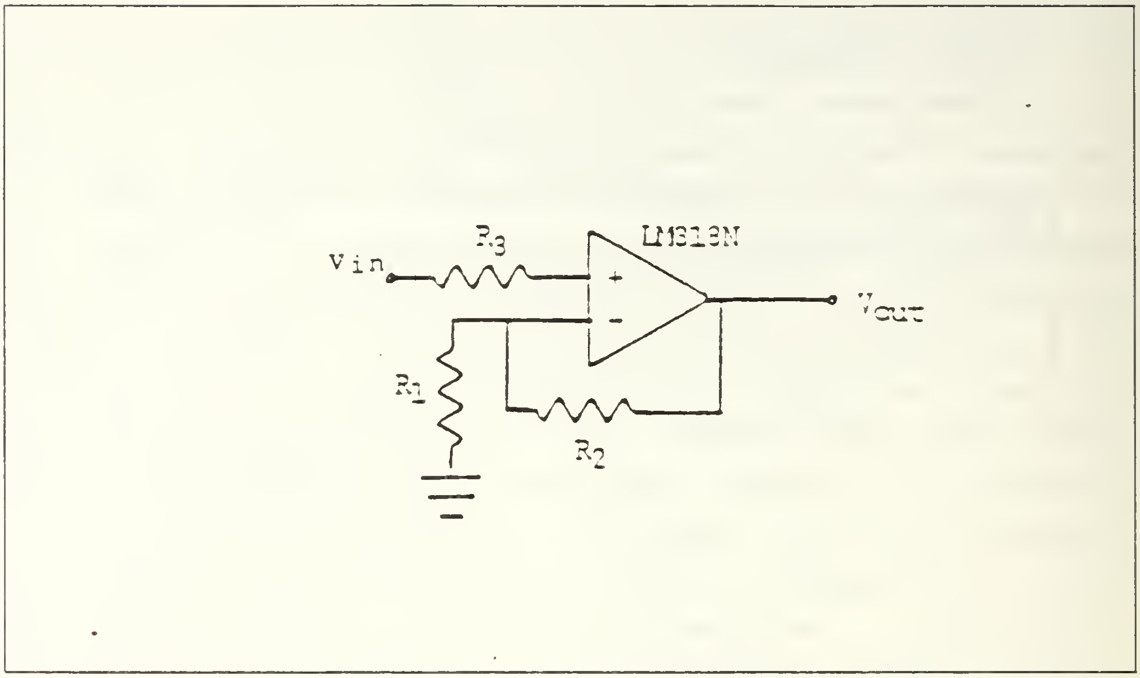

Figure 2.17a   Non Inverting Amplifier.

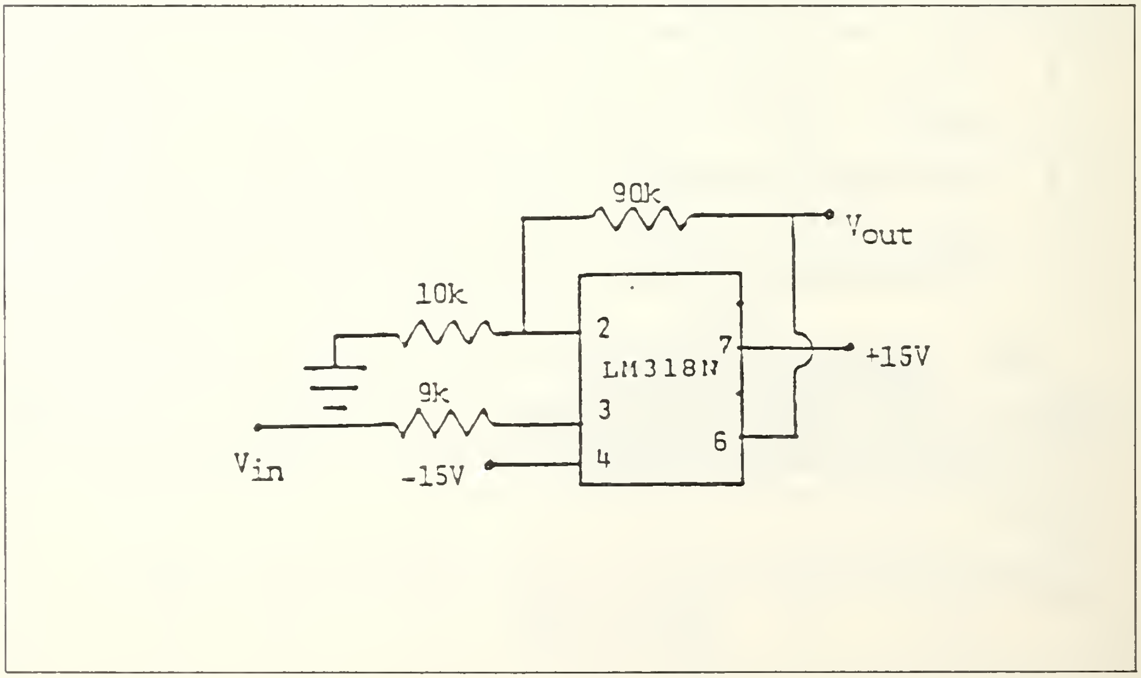

Figure 2.17b   Pin Connection.

TABLE VI

TEST OF AMPLIFIER

Input voltage (volt)	Output voltage (volt)	Gain
0.05	0.46	9.20
0.10	1.00	10.00
0.15	1.52	10.13
0.20	2.02	10.10
0.25	2.49	9.96
0.30	3.05	10.17
0.35	3.51	10.03
0.40	4.05	10.12
0.45	4.55	10.02
0.50	5.01	10.13
0.55	5.57	10.12
0.60	6.07	10.11
0.65	6.57	10.10
0.70	7.07	10.11
0.75	7.58	10.10
0.80	8.08	10.11
0.85	8.59	10.10
0.90	9.05	10.10
0.95	9.65	10.16
1.00	10.11	10.11

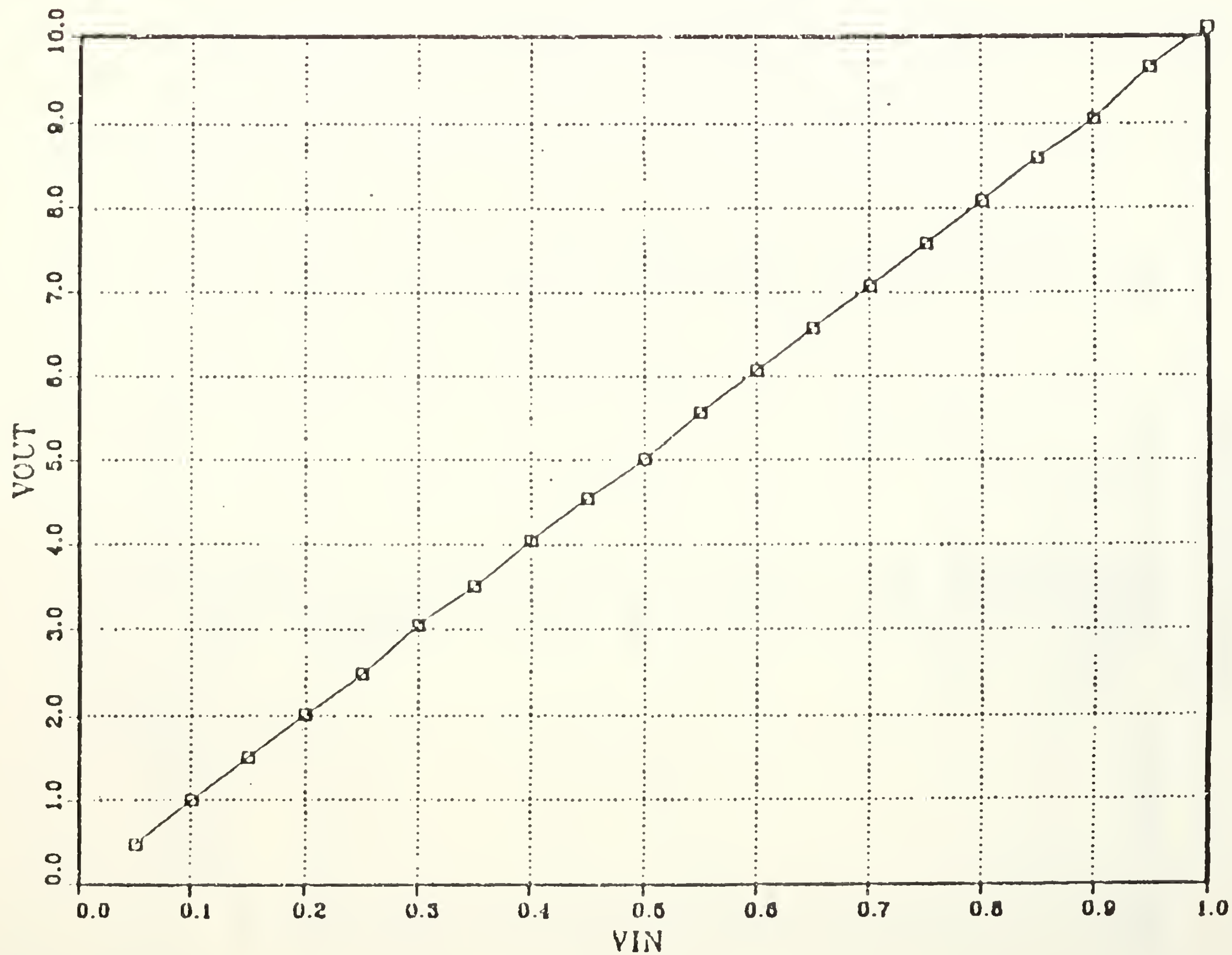

Figure 2.18 Test Results for Amplifier.

F. TOTAL SYSTEM

The total link is composed of the prescaling amplifier, the V/F converter, the F/V converter, the fiber optics link and the voltage regulators. All of these parts were connected and tested with short fiber optics. A 6 volt and 12 volt battery were combined in series to provide an 18 volt power supply to the amplifier and LM 341. It is particurly important to keep the voltage of the power supply of LM 341 over 16 volts. The measured performance of the total link is shown in Table VII and Figure 2.20. The slight deviation from ideal performance observed at input voltages of 0.65 and 0.70 occurs where the duty cycle of the pulse train goes through 50 %. It was judged that this slight error would be insignificant in assessing the status of the battery.

G. THE APPLICATION OF SYSTEM

Using this circuit, two kinds of 9-volt batteries, a lead acid battery and an alkaline battery, were tested in the laboratory for their lifetime. For this test, a voltage divider was used (Figure 2.21) to reduce the starting voltage to 1 volt and to drain enough current to hasten the discharge of the battery. The values were selected to drain the battery in a reasonable amount of time. The two 180 parallel resistors were connected in this fashion to provide sufficient power dissipation capability. The resistor values were chosen so that $R_2/(R_1 + R_2) = 0.1$. Figures 2.22 and 2.23 show the measured characteristics of the batteries' lifetimes. A alkaline battery has a longer lifetime than a lead-acid battery.

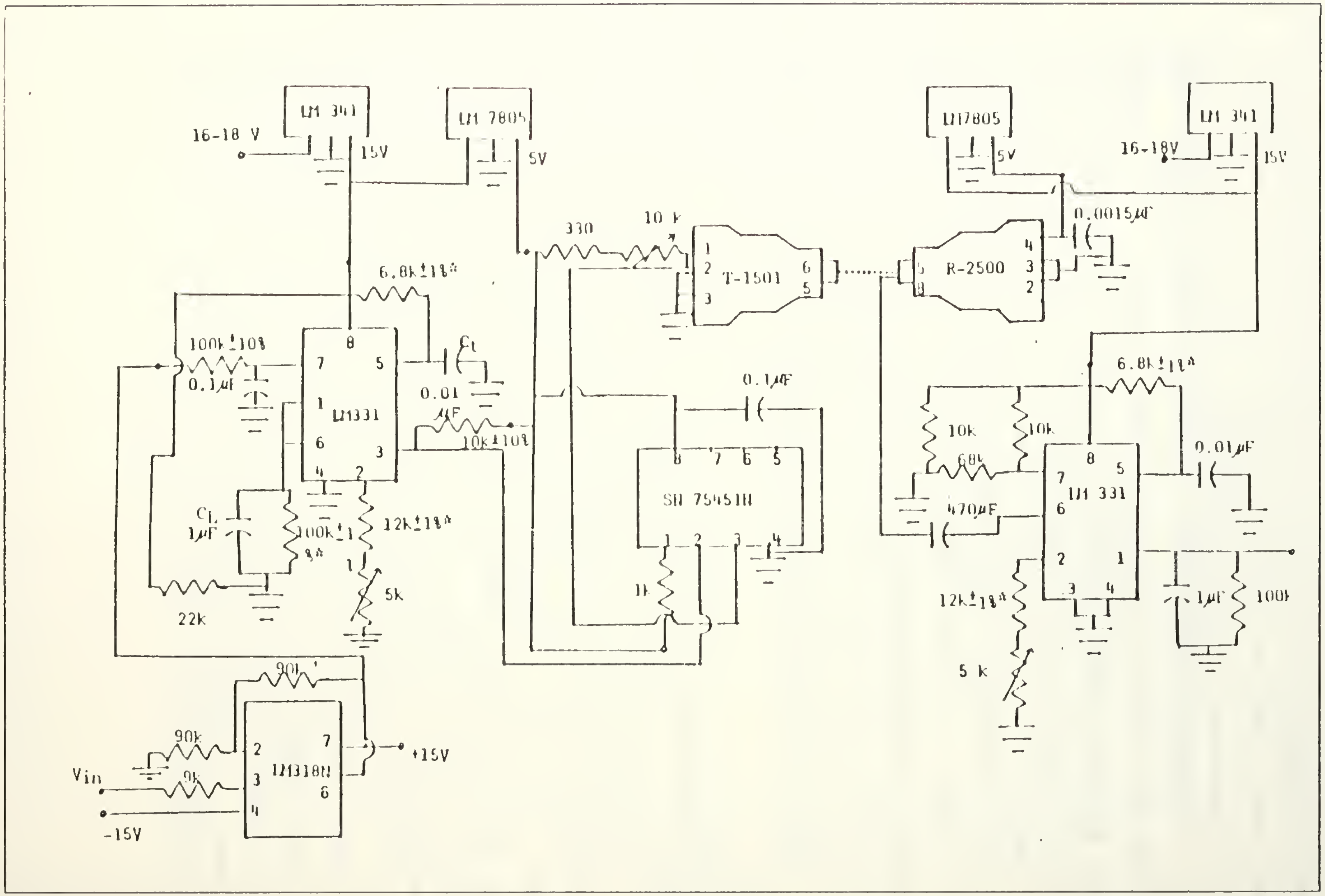

Figure 2.19 Total System.

TABLE VII

MEASUREMENT OF TOTAL SYSTEM

input voltage (volt)	output voltage (volt)
0.00	0.03
0.05	0.50
0.10	1.00
0.15	1.49
0.2	2.00
0.25	2.50
0.30	3.00
0.35	3.50
0.40	4.00
0.45	4.50
0.50	5.01
0.55	5.47
0.60	5.98
0.65	6.62
0.70	7.08
0.75	7.54
0.80	8.00
0.85	8.49
0.90	8.98
0.95	9.40
1.00	9.78

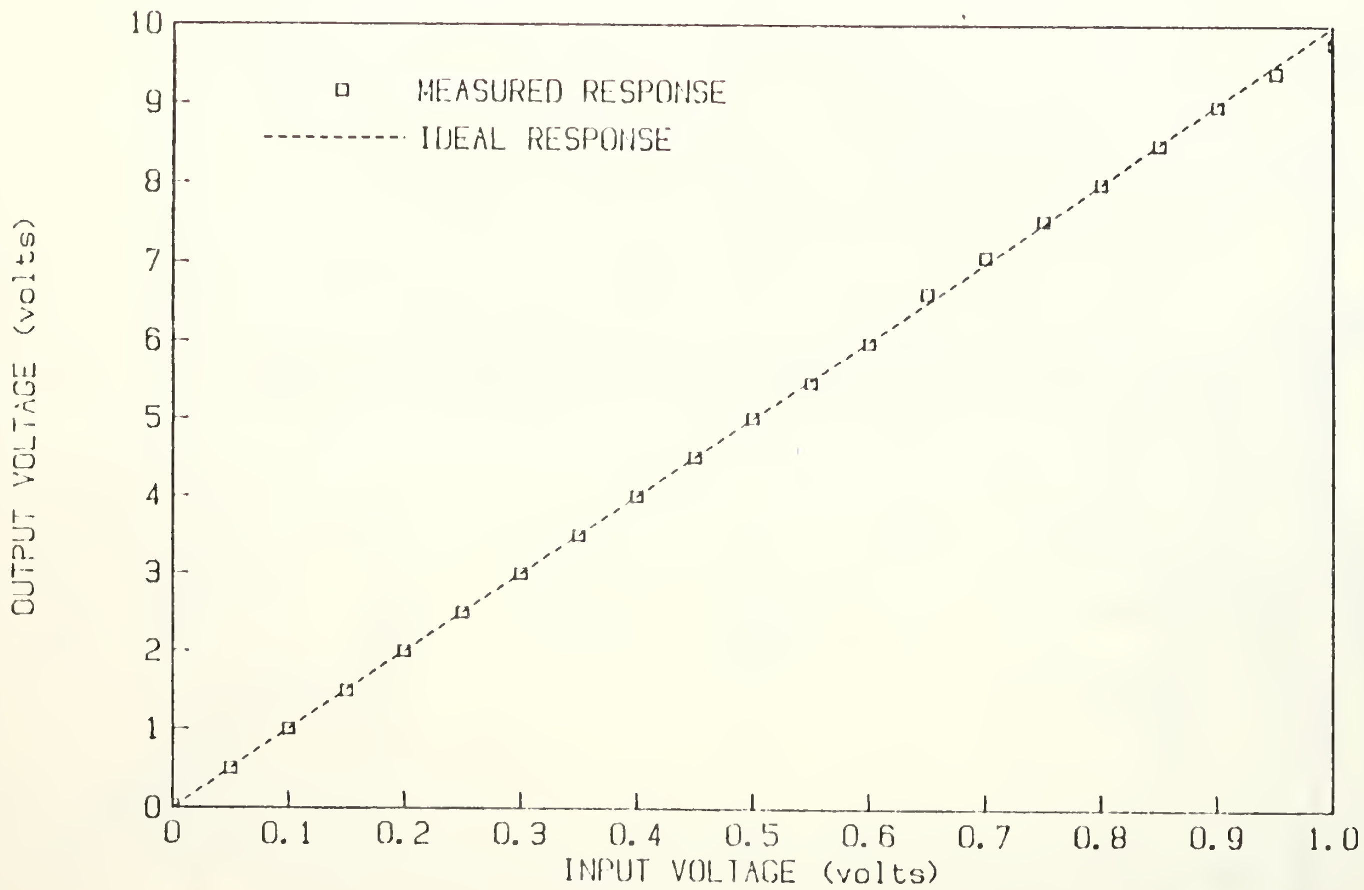

Figure 2.20 Input vs. Output Voltage.

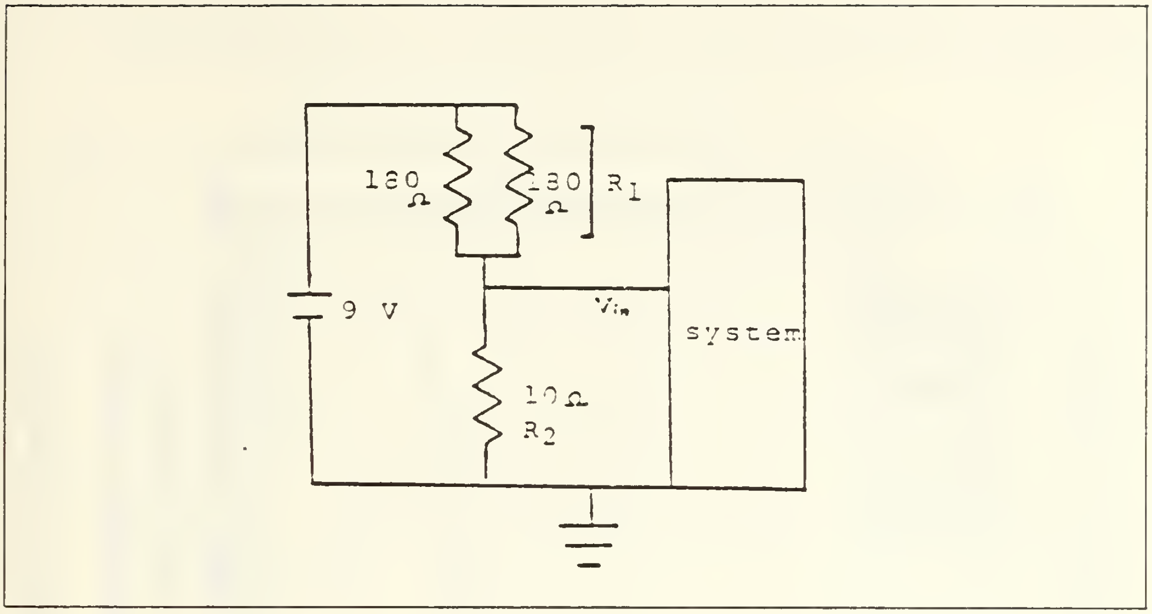

Figure 2.21   Voltage Divider.

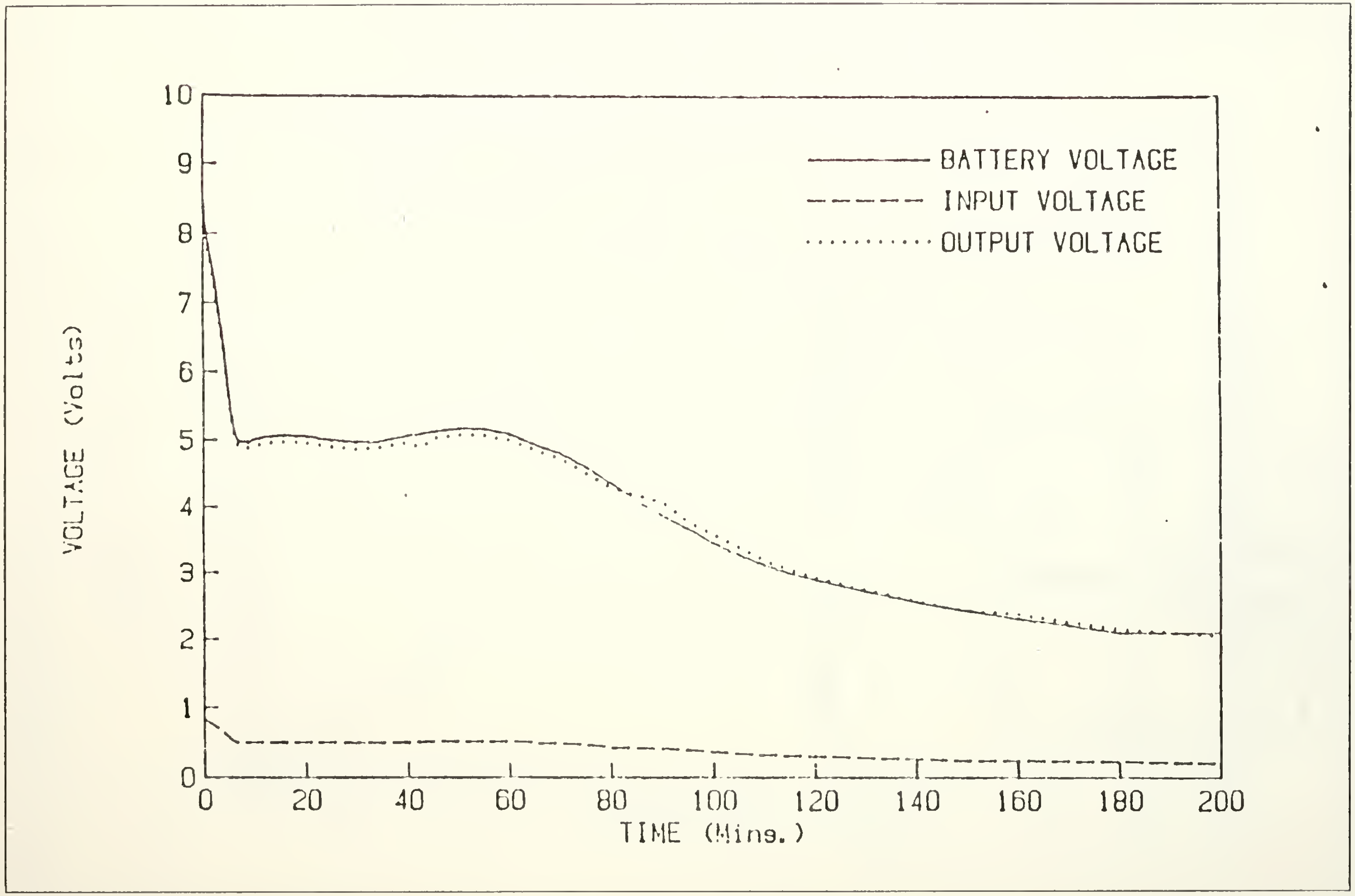

Figure 2.22 The Test of a Lead-acid Battery Lifetime.

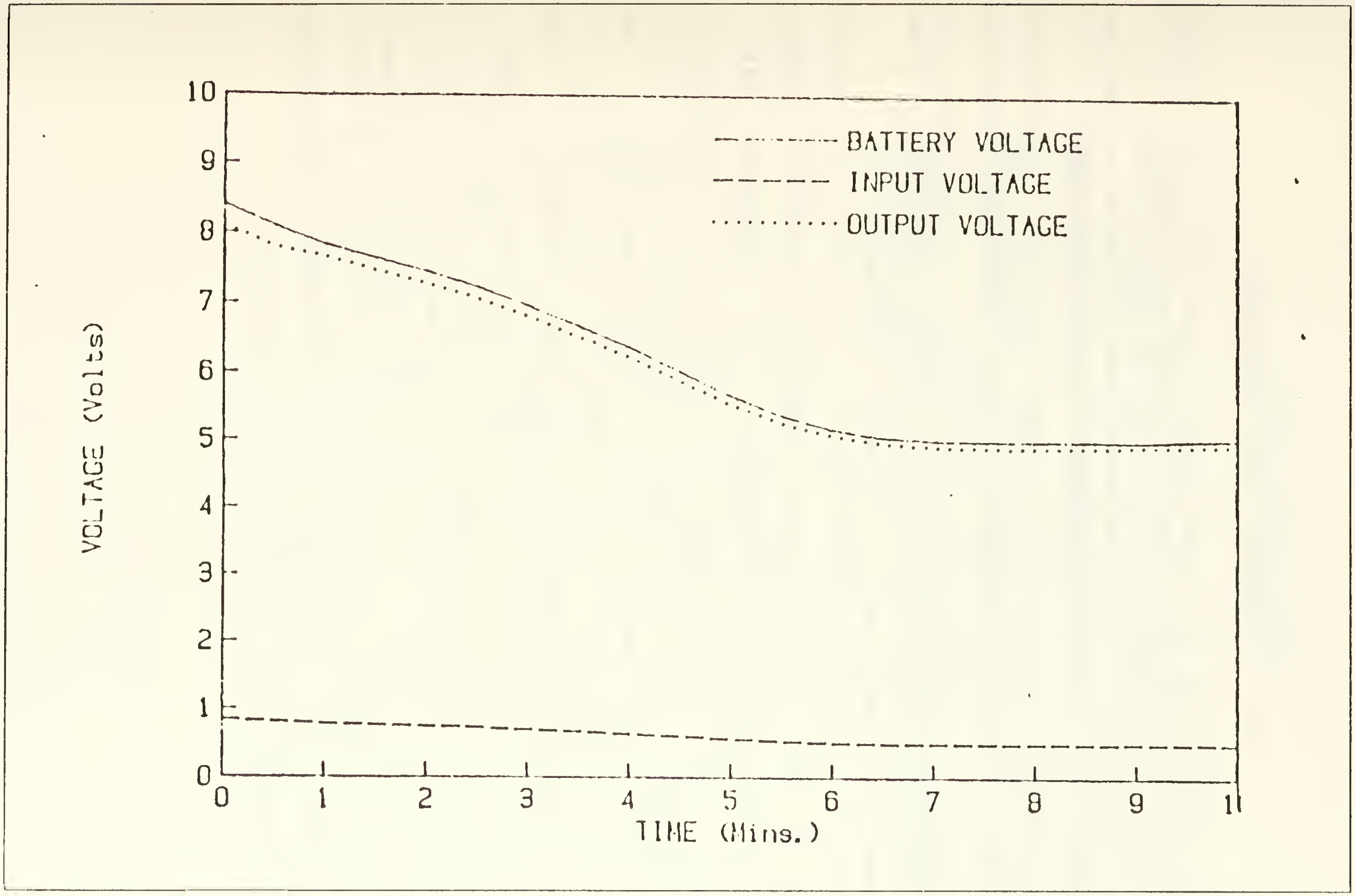

Figure 2.23 The Test of a Alkaline Battery Lifetime.

III. DISCUSSION AND CONCLUSION

The results of the measurements show that the total system has approximately 1 % errors. To reduce this error, we could use more precise components and follow more precise procedures of circuit fabrication. Also, it is important to keep the temperature constant. Under different temperature conditions, slightly different data can be shown. Because this system was designed for underwater use, however, the difference of temperature should not be significant, because the temperature under water is nearly constant.

There are problems which need to be solved. The first problem is that only one battery should be needed to supply power to the circuit. Currently, in the underwater part, one 16-20 volt battery supply is needed in V/F converter, the transmitter and the voltage regulator, and two 15-20 volt supplies are needed in the voltage amplifier. The battery powering these sources should be long-lived as it will be difficult to change this underwater battery. In the receiver and F/V converter, one 16-20 volt battery is used. It is not a problem to change this shore-based battery. This experiment was executed in a laboratory with a short length of fiber optics. If we use very long fiber and many connectors or splices, the loss will be increased. To solve this problem, low loss fiber, a more powerful transmitter and a more sensitive receiver will be required.

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